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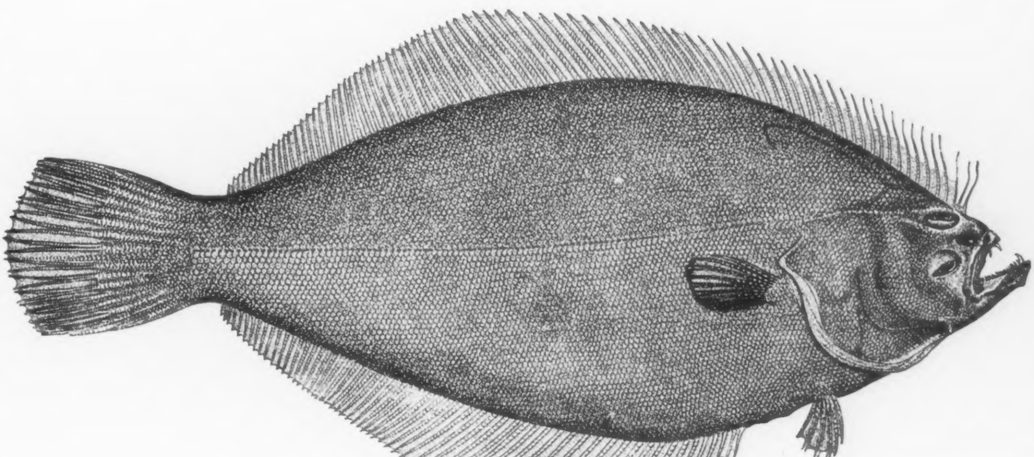

The Sand Sole

Marine Fisheries REVIEW

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On the cover:
The sand sole,
Psettichthys melanostictus.
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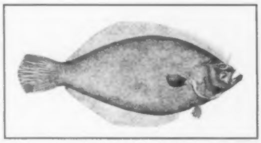

Articles — *67(4), 2005*

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Removal of Sea Lettuce, *Ulva* spp., in Estuaries to Improve the Environments for Invertebrates, Fish, Wading Birds, and Eelgrass, *Zostera marina*

CLYDE L. MACKENZIE, Jr.

Introduction

In many estuaries of North America, Europe, China, Australia, and likely other parts of the world, abundances of macroalgae have increased sharply during the latter half of the 1900's and into the 2000's. The macroalgae have increased so much that they often form huge thick mats (biomasses) on wide shoreline flats. The principal mat-forming types are sea lettuce, *Ulva lactuca* (Fig. 1), *Enteromorpha* spp., *Gracilaria* spp., and *Cladophora* spp. Few macroinvertebrates grow on the surfaces of *Ulva* spp. sheets (MacKenzie, 2000; Harder et al., 2004), and few can live beneath them (Soulsby et al., 1978; Nicholls et al., 1981; Olafsson, 1988; Bonsdorff, 1992; Norkko and Bonsdorff, 1996; MacKenzie, 2000; Rafaelli, 2000; Sfriso et al., 2001; Österling and Pihl, 2001; Jones and Pinn, 2006). The shoreline flats once provided good habitats for large numbers of macroinvertebrates that were the prey of small fishes, crabs, and shrimps, which were in turn, food for wading birds and other predators (Breber, 1985; Norkko and Bonsdorff, 1996; Thiel et al., 1998; MacKenzie and McLaughlin, 2000; Sfriso et al., 2001).

Where the algal or *Ulva* mats are present, they have covered and eliminated the areas as sources of food. In doing so, they have altered the estuaries' trophic food webs within the shallow zones and also within the entire estuaries, in part, because large commercial and sport fish in the deeper waters of estuaries had fed on some of the macroinvertebrate predators, especially the small fish (Valiela et al., 1992; Hartog, 1994; Isaksson et al., 1994; Peterson and Turner, 1994; Short et al., 1995; Norkko and Bornsdorff, 1996; Short and Burdick, 1996; Rafaelli et al., 1998; Hauxwell et al., 2001; Sfriso et al., 2001; Deegan et al., 2002; Cummins et al., 2004).

Large influxes of nitrates and also phosphates, carried by freshwater to the estuaries, have led to eutrophication of the waters and fueled the algal growth.

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ABSTRACT—Mats (biomasses) of macroalgae, i.e. Ulva *spp.,* Enteromorpha *spp.,* Graciolaria *spp., and* Cladophora *spp., have increased markedly over the past 50 years, and they cover much larger areas than they once did in many estuaries of the world. The increases are due to large inputs of pollutants, mainly nitrates. During the warm months, the mats lie loosely on shallow sand and mud flats mostly along shorelines.* Ulva lactuca *overwinters as buds attached to shells and stones, and in the spring it grows as thalli (leaf fronds). Mats eventually form that are several thalli thick. Few macroinvertebrates grow on the upper surfaces of their thalli due to toxins they produce, and few can survive beneath them. The fish, crabs, and wading birds that once used the flats to feed on the macroinvertebrates are denied these feeding grounds. The mats also grow over and kill mollusks and eelgrass,* Zostera marina. *An experiment was undertaken which showed that two removals of* U. lactuca *in a summer from a shallow flat in an estuarine cove maintained the bottom almost free of it.*

Figure 1.—Forkful of sea lettuce, *Ulva lactuca*, in the middle of a sea lettuce mat, Navesink River, N.J., July 1994.

The influxes are the result of increased urbanization and industrialization of the estuaries' watersheds (Wilkinson, 1963; Sawyer, 1965; Buttermore, 1977; Soulsby et al., 1978, 1982; Montgomery and Soulsby, 1980; Nicholls et al., 1981; Rosenberg, 1985; Valiela et al., 1997; Deegan et al., 2002; DeJonge et al., 2002).

Sea lettuce, *Ulva lactuca,* has a bright green color and imparts an apparent healthy appearance (Fig. 2). Along the east coast of the United States, its presence has not been regarded by the public as pollution-related, and its overabundance has not been particularly noticed except by boaters and swimmers who regard it as a nuisance. Many people even consider that large amounts of a green plant, such as sea lettuce, in the water denotes a healthy environment. The name lettuce also connotes to some a positive impression (like lettuce as a human food). But in Europe, sea lettuce has become regarded as a "green tide," a term somewhat analogous with brown tides and red tides that cause harm to other marine life and are also caused by eutrophication (Vasserot, 1990).

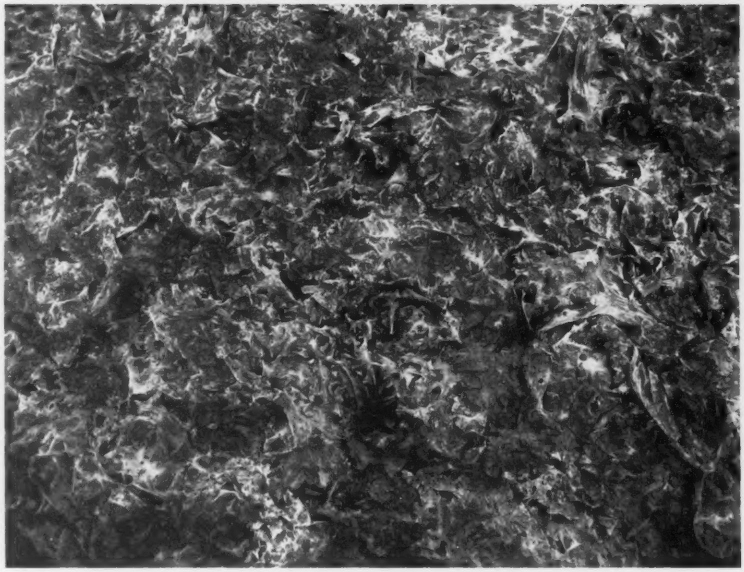

Figure 2.—Surface of a sea lettuce mat, *Ulva lactuca*, Navesink River, N.J., July 1994. Macroscopic animals and plants are nearly absent.

Autecology of Sea Lettuce

Sea lettuce, *Ulva* spp., is present in the estuaries of eastern and western North America, South America, western and southern Europe from Norway southward into the Black Sea. Sea lettuce is also found in the western Pacific from Japan, Korea, and China to Australia and New Zealand, and also in India and Pakistan (Taylor, 1957; Tseng, 1983; Lavery et al., 1991; Tagliapietra et al., 1998; Sfriso et al., 2001; Harder et al., 2004). It grows in polyhaline areas (Pirou et al., 1991; Raffaelli et al., 1998; Brush and Nixon, 2003), and the mats occur on wide gently sloping sand and mud flats in low energy areas where tidal circulations and wind-driven waves are weak. Any flats that are exposed to moderate winds commonly have scattered sea lettuce thalli (leaf fronds). In exposed areas, winds may drive scattered thalli and small mats into piles against and onto shorelines.

The thallus of sea lettuce begins as a thin, undifferentiated vegetal frond that grows quickly and takes up nutrients rapidly (Littler and Littler, 1980). Its growth is nutrient limited rather than light limited (Valiela et al., 1997). *Ulva* spp. and *Enteromorpha* spp. can take up nutrients 4–6 times faster than slower growing perennial plants (Pederse and Borum, 1997). The thalli that grow in sewage-polluted waters contain more nitrogen than those in unpolluted waters (Fritsch, 1956; Wilkinson, 1963). The thallus is two cells thick and is laminate to rounded, often somewhat lobed and undulate (Taylor, 1957), and is usually about 30 cm long and nearly as wide, but may be twice this size (Lee, 1977). The cells are uninucleate and have a single cup-shaped chloroplast. Cell division may occur anywhere in thalli, but all divisions are in a plane perpendicular to the thalli surfaces (Smith, 1955). The stalk is thin and inconspicuous or absent (Taylor, 1957).

Toxin production in marine macroalgae may be common. Harder et al. (2004) observed that the thallus surfaces of *Ulva reticula* in China are free of macroinvertebrates. Upon investigation, they discovered that the surface boundary layer of the thalli produces antifouling agents, waterborne toxic macromolecular substances of at least two types, one of which originates from the thalli and the other from an epibiotic bacterium. Magré (1974) and Johnson and Welsh (1985) showed that, in finger bowls, fragments of sea lettuce are toxic to estuarine invertebrates. Also, Anéer (1987) found that in a natural situation in Europe, the eggs of the Atlantic herring, *Clupea harengus,* were killed in large numbers by exudates released by filamentous brown algae, predominantly *Pilayella littoralis*.

The published literature reports on the sizes of sea lettuce mats in two areas. In New Jersey estuaries, the *U. lactuca* mats are from 1.5 to 75 m across (MacKenzie and McLaughlin, 2000), and in the Venice lagoon, Italy, the mats of *Ulva rigida* are as wide as 650 m (Tagliaprietra et al., 1998). But in the Three Bays Area that encompasses 1,251 acres of surface water on the south side of Cape Cod, Mass., the distribution of *U. lactuca* was more extensive than in those areas in July 2003, and it filled every one of its coves with continuous

broad mats, and the mats covered wide shallows between the coves. In various estuaries, the mats are not present in the same size mats among years (personal observations).

In the northern hemisphere, sea lettuce usually begins to cover estuarine bottoms in late April and May, and it persists into November but is scarce during the colder months (Sawyer, 1965; Nicholls et al., 1981; Soulsby et al., 1982; Kamermans et al., 1998; Tagliapietra et al., 1998). In winter, sea lettuce is present as buds attached to pebbles and empty shells, such as mud snails, *Ilyanassa obsoleta*, or as thallus fragments partly buried in surficial sediments (Kamermans et al., 1998). In the spring, new thalli grow from both buds and fragments and within a few weeks grow to full size. The earliest stage of a mat is a single layer of thalli, but eventually several free-floating thalli aggregate into layers forming a mat. Layering can be substantial, and the mats are often about 30 cm thick resting loosely on the bottom (Welsh, 1980; Hernández et al., 1997; MacKenzie and McLaughlin, 2000; Brush and Nixon, 2003). The layers are closely packed, and water flows slowly or not at all through the interstices between them. The thalli of mats near the bottom eventually die, become anoxic, black, and produce hydrogen sulfide gas. The rotting material penetrates into the sediment and creates anoxic conditions therein (Nicholls et al., 1981; Krause-Jensen et al., 1999; Brush and Nixon, 2003).

In some small protected coves, large mats of sea lettuce decay in such large volume in the autumn that the sediments remain permanently covered with a mass of black organic material. In the same areas, the decaying sea lettuce produces gasses that have an unpleasant odor and can blacken the oil paint of nearby houses due to the formation of lead sulfide (Wilkinson, 1963; Sawyer, 1965).

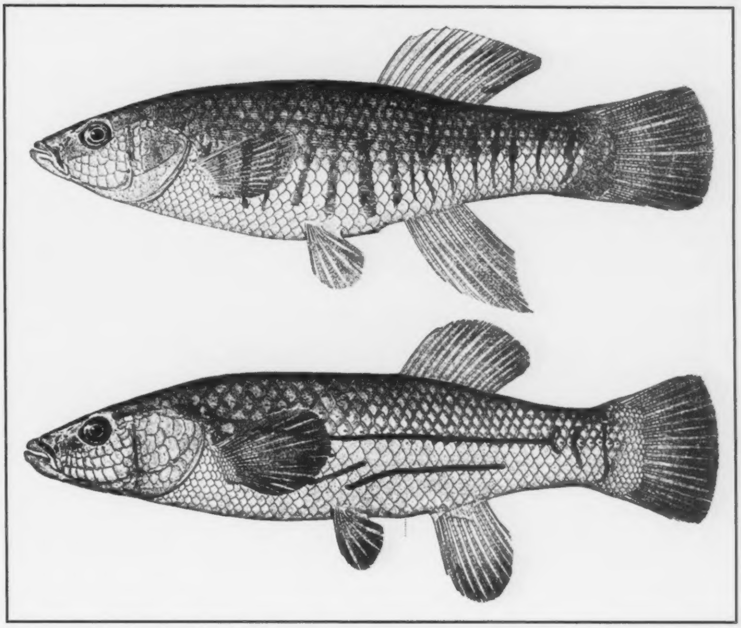

Figure 3.—Adult striped killifish, *Fundulus majalis* (female, top; male, bottom), about 10 cm long (TL). From Bigelow and Schroeder, 1953.

The Biological Environment of Estuarine Shallow Zones

The estuaries in the eastern United States that contain little sea lettuce (and this was the status of most before they became eutrophic) commonly are bordered by marshes shoreward with deeper water offshore. Their broad shallow zones provide habitats for large numbers of macroinvertebrates (arthropods, polychaetes, mollusks, and others) and decapods, including blue crabs, *Callinectes sapidus*, and shrimp; juvenile and adult killifish and mummichogs, *Fundulus* spp.; and commercially-important mollusks. The fish may also include Atlantic silversides, *Menidia menidia*; bay anchovies, *Anchoa mitchilli*; spot croaker, *Leiostomus xanthurus*; fourspine sticklebacks, *Apeltes quadracus*; American eels, *Anguilla rostrata*; and northern pipefish, *Syngnathus fuscus* (Subrahmanyam and Drake, 1975; Daiber, 1982; Able and Fahay, 1998; Deegan et al., 2002), and their eggs and larvae (Daiber, 1982). Some shallow zones support meadows of eelgrass, *Zostera marina*, that comprise their own habitat, and they have a role in stabilizing sediments and shorelines (Belding, 1909; Thayer and Stuart, 1974; Orth, 1977; Fonseca et al., 1982, 1998; Weinstein and Brooks, 1983; Reise, 1985; Sogard and Able, 1991).

In the eastern United States, the killifish and mummichogs (Fig. 3, 4) are the primary transients that move back and forth between the shallows and deeper water with each rise and fall of the tide to feed on the macroinvertebrates (Hettler, 1989; Kneib and Wagner, 1994; MacKenzie and McLaughlin, 2000). The extent that crabs and shrimp may move back and forth similarly is unknown.

Many of the macroinvertebrates feed on filamentous algae, diatoms, and detritus (Daiber, 1982). Striped killifish and mummichogs feed on amphipods and isopods and also the juveniles of several mollusks, including softclams, *Mya arenaria* (Fig. 5); eastern melampus, *Melampus bidentatus*; mud snails; Atlantic slipper snails, *Crepidula fornicata*; and juvenile polychaetes and horseshoe crabs, *Limulus polyphemus* (3 mm). Some sea lettuce, insects, and detritus are also eaten (Vince et al., 1976; Kneib and Stiven, 1978; Daiber 1982; MacKenzie and McLaughlin,

2000). MacKenzie and McLaughlin (2000) observed that killifish guts were about 3/5 full of food items when collected, but the food passes through them quickly: 80% of that passes through in 3 h, and 100% in 24 h. This suggests a high consumption rate. Blue crabs feed mainly on mollusks and also consume some polychaetes (Meise and Stehlik, 2003). The shrimp feed mainly on diatoms, dinoflagellates, and tiny crustaceans, such as copepods (Bello-Olusoji et al., 2005) .

In the deeper waters, some adult killifish and mummichogs and the other transient fishes are eaten by such larger fish as striped bass, *Morone saxatilis*; bluefish, *Pomatomus saltatrix*; weakfish, *Cynoscion* spp.; and others (Hildebrand and Schroeder, 1928; Kneib and Stiven, 1978; Collette and Klein-MacPhee, 2002). While the killifish and mummichogs have no commercial importance, except for sale as bait, their tidal movements into the shallow flats and back to the deeper estuarine environments comprise a trophic link between the macroinvertebrates and the larger sport and commercial fish in the estuaries (Butner and Brattstrom, 1960; Subrahmanyam and Drake, 1975; Kneib and Stiven, 1978; Weisberg and Lotrich, 1982; Ryer, 1987; McIvor and Odum, 1988; Kneib and Wagner, 1994).

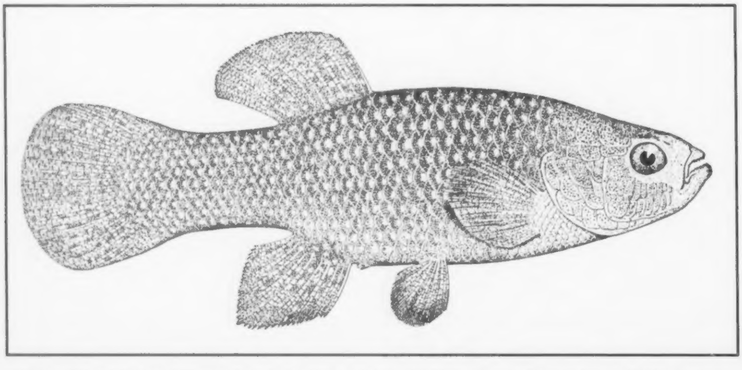

Figure 4.—Adult mummichog, *Fundulus heteroclitus*, about 11 cm long (TL). From Bigelow and Schroeder, 1953.

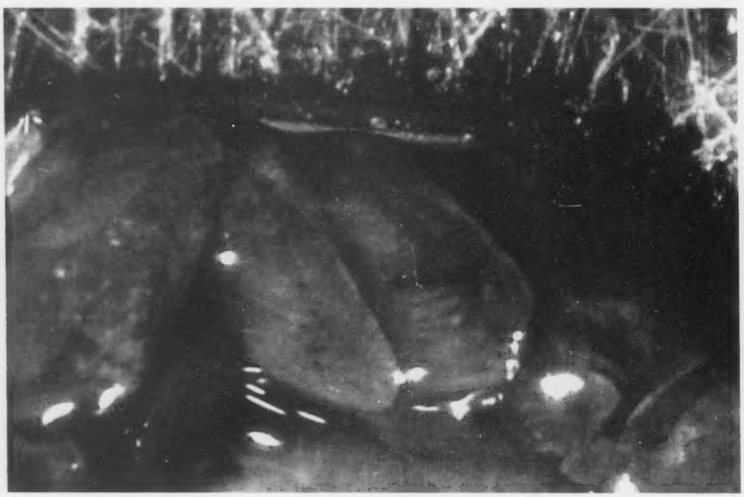

Figure 5.—Softshell clams, *Mya arenaria*, in the gut of a striped killifish, *Fundulus majalis*, from the Navesink River, N.J., July 1994. The softshells when whole were about 10 mm long.

In the eastern United States, the inner edges of the estuarine shallows are also feeding areas for wading birds, particularly great blue herons, *Ardea herodias*; green herons, *Butorides virescens*; great egrets, *Casmerodius albus*; and snowy egrets, *Egretta thula*. They stalk fishes including killifish and gobies in the shallows (Weise and Smith-Kenneally, 1977). The foods of willets, *Catoptrophorus semipalmatus*, and clapper rails, *Rallus longirostis,* consist of aquatic insects, polychaetes, small crabs, mollusks, fish larvae and small fish (Bent, 1929, 1963). Over 80% of the diet of seaside sparrows, *Ammodramus maritimus*, consists of marine insects, small crabs, and snails. Saltmarsh sharp-tailed sparrows, *Ammodramus caudacutus,* eat insects, amphipods, and small snails. The birds that feed in the shallows also include grebes (Podicipediformes), various ducks and swans (Anatidae), gulls (Laridae), terns (Sternidae), and belted kingfishers, *Ceryle alcyon* (Bent et al., 1968).

How Macroalgal Mats Have Degraded Estuaries

The development and spread of the mats of sea lettuce and the other macroalgae have degraded estuarine environments. They have altered water chemistry, nearly eliminated large sections of their shallows as feeding zones of fish, arthropods, and birds (Baird and Milne, 1981; Hull, 1987; Raffaelli and Milne, 1987), and they have overgrown and killed mollusks and eelgrass.

Chemical Alterations

The sea lettuce mats remove some nitrates and phosphates and other nutrients from the water as they grow and metabolize, but when they die and disintegrate each October and November they release them back to the water. This

release sustains the highly eutrophic condition of the ecosystem (Naldi and Viaroli, 2002). A series of biochemical effects that are likely to affect entire food webs follows (Perkins and Abbott, 1972; Valiela et al., 1997; Deegan et al., 2002).

Seasonal Effects on Macroinvertebrates

Sea lettuce has reduced the number of macroinvertebrates on the sediment surfaces of estuarine shallows at least threefold in the Venice lagoon, Italy (Tagliapietra et al., 1998; Sfriso et al., 2001), and nearly 100% in Jamaica Bay, New York (Franz and Freidman, 2002). To estimate the effects of *U. lactuca* mats in the Navesink River, New Jersey, MacKenzie (2000) counted the combined numbers of nematodes, harpacticoid copepods, amethyst gem-clams, *Gemma gemma*, polychaetes, and eastern mudsnails, *Ilyanassa obsoleta*, per unit area, in unvegetated sediments next to sea lettuce mats and in sediments under the mats. The unvegetated sediments had an average number of 2,117/area while the matted sediments had 57/area, a 37-fold difference. The negative effects of the mats are further pronounced because their maximum bottom coverage, June through August, coincides with the main time when the larvae of the fauna would settle onto the sediments (Bonsdorff, 1992; Bonsdorff et al., 1995; Norkko and Bonsdorff, 1996).

Tagliapetra et al. (1998) described how the seasonal occurrences of *U. rigida*, affect the infauna in the Venice lagoon, Italy. In May and June, the sea lettuce grows over and kills nearly all the invertebrates and their numbers remain low for 9–10 months from June into February and March. The sea lettuce dies in the fall, decomposes, and enriches the bottom sediments with organic matter. During the following spring, juvenile invertebrates settle and then survive and grow well. The subsequent mats of sea lettuce grow over them and the annual cycle is repeated. A patchy distribution of sea lettuce mats produces discrete patterns of infaunal distribution in the Venice lagoon and elsewhere (Everett, 1991; Sfriso et al., 2001).

Overgrowth of Clams

The macroalgal mats have overgrown and killed clams. Breber (1985) found that mats of *Ulva rigida* and *Gracilaria* spp. kill carpet-shell clams, *Tapes decussatus*, in Italy. Thiel et al. (1998) observed that overgrowths of *Enteromorpha prolifera* kill softshell clams in Maine. MacKenzie and McLaughlin (2000) reported that overgrowths of *U. lactuca* killed softshell clams in New Jersey; initially, the clams emerged from the sediment, then laid on the bottom, and ultimately died (Fig. 6). In addition, Everett (1994) observed that bent-nose macomas, *Macoma nasuta*, were more abundant in areas devoid of *Ulva expansa* than in areas where it formed mats in California.

Degraded Feeding Habitats of Wading Birds

Wading birds normally feed at the edges of marshes at low tide but not where sea lettuce is abundant. Nicholls et al. (1981) and Jones and Pinn (2006) observed that wading birds avoid algal mats, probably because their prey is not available.

Overgrowth of Eelgrass

In some estuaries, the algal mats have also overgrown and killed eelgrass and other seagrasses (Valiela et al., 1992). The extent of this is not precisely known, but Hauxwell et al. (2001) conclude that eelgrass losses from this overgrowth may be quite large worldwide.

Figure 6.—Mass of dead softshell clams, *Mya arenaria*, in the Navesink River, N.J., August 1994. The clams were smothered by an overgrowth of sea lettuce, *Ulva lactuca*, emerged from the bottom sediments, and died. Most softshells are 40–45 mm long.

Faunal Species That Sea Lettuce Mats Benefit

Relatively small mats of sea lettuce may be beneficial in estuaries, because their edges can be focal points for fishes and crustaceans, and they provide refuges from predators (Heck and Thoman, 1984;Wilson et al., 1990; Ferrell and Bell, 1991; Kneib and Wagner, 1994; Timmons, 1995). In the Navesink River, New Jersey, large age-0 winter flounder are strongly associated with small habitats vegetated with *U. lactuca*, and young-of-the-year oyster toadfish, *Opsanus tau*, can use sea lettuce as a habitat (Stoner et al., 2001). Fish in small sea lettuce mats had lower mortality than they did when over bare sand and lower mortality in eelgrass meadows than in sea lettuce meadows. Prey vulnerability appeared to be related to the role of vision in the predators' attack strategy and prey activity levels (Manderson et al., 2000).

In the Little Egg Harbor–Great Bay estuary in southern New Jersey, Sogard and Able (1991) found that small mats of sea lettuce harbored more fish and decapods than the adjacent unvegetated habitats. Sea lettuce was an important habitat in areas that lacked eelgrass, but for the decapods the eelgrass and sea lettuce provided habitats of equal quality.

The primary foods of brant, *Branta bernicla*, a type of North American goose, have been known to be eelgrass, widgeon grass, *Ruppia maritima*, and sea lettuce. But since the eelgrass meadows have become scarce, first noted during the 1930's, the brant have eaten mainly sea lettuce (Trippensee, 1953; Burger, 1996).

Controlling Mats of *Ulva* spp.

The best way to reduce eutrophication and its negative effects is to control it at its source by reducing the quantities of nutrients, especially nitrates, that enter estuaries. In lieu of that, manual removal of algal mats can be an alternative means to help return the estuaries to their pre-eutrophic condition, although another harmful effect of eutrophication, the presence of dense phytoplankton blooms, would remain.

In 1994, my experience with removing sea lettuce from a shoreline flat in a sheltered area in the Navesink River, New Jersey, showed that two removals were sufficient to maintain the flat nearly free of it. Each time the sea lettuce was removed, the mat was only one thallus thick, and consequently the quantity handled was relatively small.

The test area was located along the edge of a cordgrass, *Spartina alterniflora*, marsh. The test area measured 20 m long and 20 m wide. The water depth at low tide was 0.1 m along its inner edge and 1 m deep along its outer edge. The thalli had begun to grow in late April and by early June they had nearly covered the bottom with a single floating layer. The sea lettuce was removed then with an 18 m minnow seine, which extended from the water surface to the bottom. Scattered pieces of thalli remained, but nearly the entire benthic habitat was free of this layer of sea lettuce. The thalli pieces began to grow, and by early September the test area again was covered with a single layer of thalli. The area was cleared of the sea lettuce again with the same minnow seine at that time. The remaining pieces of thalli began to grow again, but they did not cover the area in a single layer before they began to disintegrate and decompose in the autumn. Space was available consistently for fish, crabs, and birds to feed in the test area.

A floating machine, like those used in freshwater lakes to control aquatic weeds, might be effective in controlling algal mats in large areas. The machines collect grasses with whirling rakes around a spoke. They have a shallow draft, they are propelled by paddlewheels, and they deliver grasses to beaches. Trucks can haul them to composting facilities (Lockwood, 2002). In small areas, haul seines and even hand rakes can be used to remove sea lettuce (Town of Harwich, Mass.[1]).

[1]Town of Harwich, Mass., Nat. Resourc. Dep. 2004. Harwich Sea Lettuce Control Project. Conservation Commission Approval (negative determination)Tuesday, 12Jan. 1998.Availableonline at: http://www.vsa.cape.com/harharb/sealettucecontrol.html. Site assessed and printed 1 June 2004.

Mazé et al. (1993) recommends that collections of sea lettuce should be composted with a small quantity of lingocellulose substrate to stabilize them. Otherwise, storage of non-composted sea lettuce results in objectionable odors and the release of some liquid. The composted product can be used as fertilizer. If sea lettuce is left piled on shores, some nitrogen will escape to the air and some will leach back into the water. Such piled sea lettuce attracts flies.

Conclusion

Many studies have demonstrated that the prolific growths of macroalgae, especially sea lettuce, have degraded the environments of estuaries. Removal of the macroalgae would help to restore the shallow habitats to their former condition. The macroinvertebrates would become abundant, the feeding grounds of fish, arthropods, and birds would be restored, more clams would survive, some eelgrass meadows might return, and likely more small fish and perhaps arthropods would become available as food for larger fish in the deeper waters. Moreover, some excess nitrate and phosphate would be removed from the estuaries. The actions to remove sea lettuce from the shallows would not remove all the thalli, and there likely would be some remaining for the various fauna to use as cover and food. Brant are not present in many locations where sea lettuce occurs, and, where they are present, they appear to consume only a moderate amount of the available sea lettuce. Brant might be only lightly affected if the sea lettuce was partly removed from the few areas where they congregate and feed. The overall benefits of removing most of the macroalgae would seem to far outweigh any of the potential small negative effects.

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Age, Growth, Life History, and Fisheries of the Sand Sole, *Psettichthys melanostictus*

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Introduction

Sand sole, *Psettichthys melanostictus*, is a common nearshore pleuronectid flatfish in the northeast Pacific Ocean. Also known as fringe sole, spotted flounder, or sand flounder, this species is often caught recreationally from shore, and it also makes up a small part of commercial trawl catches (Kramer et al., 1995). Commercial landings of sand sole in California, Oregon, and Washington have brought in over $11 million between 1981 and 2004 (PacFIN, 2005). In comparison, Dover sole, *Microstomus pacificus*, the most abundant commercial flatfish on the west coast of the United States, was valued at $200 million in the same period.

Although the sand sole's overall economic value is low, it consistently commands a high price per pound, with only three other flatfish species commanding a higher price (California halibut, *Paralichthys californicus*; Pacific halibut, *Hippoglossus stenolepis*; and starry flounder, *Platichthys stellatus*). As a comparatively minor commercial and recreational species, and with little data available, sand sole has never been the subject of a formal stock assessment, nor is one likely to be conducted in the near future.

The sand sole ranges from the Bering Sea (Allen and Smith, 1988) to Redondo Beach, southern California (Fitch and Schultz, 1978). It is common on sandy bottoms at depths <70 m (Kramer et al., 1995), but it has been taken as deep as 325 m (Allen and Smith, 1988).

Previous studies have described the growth and life history of sand sole larvae and juveniles (Hickman, 1959; Sommani, 1969), but little has been reported about the adult life history of this species. Virtually all previous sand sole studies have been conducted in Oregon, Washington, and Canada, but little is known about its California populations. Furthermore, no studies have been published on the fisheries for this species.

This study was conducted to determine the age, growth, spawning season, life history, and sex ratio of California sand sole populations and to compare them to published values from other areas. In addition, we describe the fishery to evaluate whether there was any evidence of a decline in abundance and determine where the fisheries were conducted. We also reviewed the scientific literature on sand sole and compared our results to previous studies. We also present, to the best of our knowledge, the first attempt at age validation.

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ABSTRACT—Sand sole, Psettichthys melanostictus, *is a small but important part of the west coast groundfish fishery. It has never been assessed and there is a limited amount of biological data for the species. We provide the first estimates of age and growth for California populations and compare them with studies from other areas. We found that sand sole is a rapidly growing species which may show a strong latitudinal gradient in growth rate. We also found evidence of a recent, strong cohort-related shift in the sex ratio of the population towards fewer females. In addition we examined data from the Washington, Oregon, and California commercial fishery to make an initial determination of population status. We found that catch per unit of effort in commercial trawls experienced a decline over time but has rebounded in recent years, except central California (the southern part of its commercial range), where the decline has not reversed.*

Materials and Methods

Collection of Samples

Samples of adult sand sole were collected by trawl net off central California in the vicinity of Monterey Bay, during 39 tows conducted between November 2001 and March 2005. Sampling equipment consisted of a commercial bottom trawl net with a 4.6 m vertical opening, 41.2 m footrope, and a 10.2 cm mesh in the codend. A net liner with 1.3 cm mesh was inserted in the codend. The net was towed at a ground speed of about 2.5 knots, typically for 1 h. Tows were made at various depths between 20 and 600 m.

Fish were processed onshore to determine fork length (FL) to the nearest millimeter, weight in grams, sex, and maturity. Sagittal otoliths were removed and stored dry in coin envelopes. Sex was determined by dissection and examination of the gonads. Our previous experience suggested that determining maturity state for flatfish is difficult without careful microscopic examination. To assign a maturity state, we classified females as mature if eggs were clearly visible and could be easily separated, or if there was evidence of recent egg release (i.e. loose oocytes within the ovary). If the ovaries were small and no eggs were apparent, we classified the fish as immature. In cases where no oocytes were readily visible to

the naked eye, but the ovaries were large, we classified the maturity as unknown. Males were classified as mature if either sperm ran freely or the testes were enlarged and well developed. Males were classified as immature if the testes were small and translucent. If the testes were intermediate, the maturity state was classified as unknown.

Age and Growth

To validate yearly annulus formation, we examined the whole sagittal otoliths of 226 fish under 25× magnification using ScionImage processing software.[1] Presumed annuli were measured along the dorso-ventral axis through the nucleus. Sand sole otoliths are asymmetrical with respect to one another: the left otolith has annuli oriented around the center of the otolith, whereas in the right otolith, the core is closer to the posterior end. This asymmetry between left and right otoliths was evident in all sizes of fish that we examined.

We chose to use only the left otolith for validation in this study for three reasons: 1) the annuli were generally more distinct and were easier to read on the left otolith, 2) the central axis of the annuli corresponded more closely with the central axis of the otolith, and 3) the annuli were slightly wider than those of the right otolith, reducing the likelihood of errors in measurement. We measured along the dorso-ventral axis since the annuli were more regularly shaped, than along the somewhat longer anterior-posterior axis.

Only the diameters of the first three presumed annuli (if present) were measured. We chose not to attempt to measure more than three annuli since the annuli became quite close together with age, making it difficult to obtain accurate measurements. Otoliths from male and female fish were measured separately to account for possible differences among the sexes. A marginal increment analysis was attempted, but it proved to be inconclusive due to the difficulty of determining edge type on many of the fish, particularly older ones.

This study utilized a combination of surface readings and the break-and-burn method (Chilton and Beamish, 1982) to determine the ages. Generally, fish larger than 340 mm FL were aged using the break-and-burn method, while surface readings were used for smaller fish. Surface ageing was performed at 15× magnification, while break-and-burn readings were done at 20–30× magnifications. Lengths at estimated age were fitted to a von Bertalanffy growth curve by least squares. The form of the equation was:

$$L_t = L_\infty\,(1 - e^{-K(t - t_0)})$$

where L_t = fish length (mm FL) at age t (years),
L_∞ = average maximum length (mm FL),
K = growth completion rate (per year),
t_0 = theoretical age (in years) when the fish was length zero.

Parameters for the growth curve were computed iteratively using the method described by Schnute (1981). Growth curves were fitted separately for males and females to account for possible sex-specific growth rates.

We estimated a weight-length relationship by applying a nonlinear regression, fitting the equation $W = aL^b$, where W = weight (g), L = Length (cm FL), where a and b are fitted parameters (Ricker, 1958). Body length was converted to centimeters for this equation to more easily compare our estimates with previous studies.

We used three methods to estimate the natural mortality rate of sand sole: the Hoenig (1983) method based on longevity, the Lorenzen (1996) method based on maximum weight, and the Beverton (1992) method based on growth rate. For this analysis, we combined commercial sample data and research samples to increase sample size.

To estimate total mortality rate (Z) we examined the catch-at-age from the research samples using the Heincke method (Heincke, 1913) as described in Ricker (1975). In this method, the change in catch of the descending catch-at-age plot is used to estimate Z.

Fisheries Data

Annual estimates of commercial landings in California, Oregon, and Washington were obtained from the Pacific Fisheries Information Network (PacFIN, 2005), and summarized by the five International North Pacific Fisheries Commission (INPFC) areas: Conception, Monterey, Eureka, Columbia, and U.S.–Vancouver. The Conception INPFC area is south of lat. 36°N, and the Monterey INPFC area is between lat. 36°N and 40°30′N. The Eureka INPFC area is between 40°30′N and 43°N. The Columbia INPFC area is between 43°N and 47°30′N. The U.S.–Vancouver INPFC area is from lat. 47°30′N to the U.S.–Canada border including the Puget Sound.

We obtained recreational landings estimates for sand sole landings from the Recreational Fisheries Information Network (RecFIN, 2005). The recreational data provided estimates of metric tons of fish caught in California, Oregon, and Washington combined from 1980 through 2004.

Commercial trawl logbook data were obtained from PacFIN (2005) and catch per unit effort (CPUE) was calculated for depths and areas where sand sole were most abundant. To determine the areas and depths of greatest sand sole abundance, we summed reported logbook catches by degree of latitude and by depth interval. By visual inspection of the plots, we determined regions of the coast where sand sole were caught most frequently.

To determine the commercial catch depth distribution, we summed catches by depth and selected the depth range which accounted for 95% of the catch. Since the sand sole is a comparatively minor species, we also wanted to determine how well it was identified in logbooks. To test this, we compared annual landings by state from the logbooks to the reported landings from the PacFIN database which relies on landing receipts.

[1]Scion Image 4.0.2, Scion Corporation, Frederick, MD 21701. Mention of a product name does not imply endorsement by the National Marine Fisheries Service, NOAA.

Very little length data are available from the commercial fishery for sand sole; however, we were able to use some sample data collected by the California Cooperative Groundfish Program, which conducts commercial market sampling of groundfish in California (CALCOM, 2005).

Results

Research Catch

A total of 540 females, 239 males, and 33 unsexed fish were collected in 39 tows (Table 1). Data from the unsexed fish were used only when male and female data were combined. Most specimens were collected in less than 50 m of water (Table 2). Individuals ranged from 116 mm to 477 mm FL (Fig. 1).

Age Validation

Of the 226 otoliths examined for age validation, 75 were from males and 151 from females. Mean diameters of the second and third presumed annuli were notably different between sexes, with females having larger annuli on average (Fig. 2). For both sexes, the presumed second annulus presented the most variability, overlapping considerably the ranges of the first and third.

The overlap problem was resolved by comparing the range of annuli diameter within cohorts, after production ageing was completed. For instance, the standard deviation for all female second annuli combined was 0.45 (n =102), but only 0.39 (n = 34) for females subsequently estimated to be born in 1998. Thus, different cohorts appear to have different annuli sizes, at least for the first 3 years of life, suggesting differences in otolith growth rates among years.

A marginal increment analysis (Hyndes et al., 1992) proved inconclusive due to numerous false marks, but Smith (1936) found that translucent (hyaline) zones were formed between January and March. Thus, we conclude that only one annulus is formed per calendar year.

Age and Growth

The oldest female fish aged in this study were two 8-year-old fish, while the oldest males were three 6-year-old fish (Fig. 3). The majority of females were 2–4 years old, while the males were mainly 1–3 years old.

Our estimated von Bertalanffy growth curve parameter estimates indicated that sand sole grow very rapidly with K values of 0.60 and 0.79 for males and females, respectively (Table 3). Average maximum length (L_∞) was substantially different for males and females, with females reaching a much larger size (376 mm for females as compared to 310 mm for males).

In this study we estimated the weight-length relationship to be W (grams) = 0.0175 $FL^{2.8294}$ for males, and W = 0.00674 $FL^{3.1367}$ for females. The sample size for males was 116, the r^2 was 0.89, and the range in lengths was 130 to 376 mm. The sample size for females was 269, r^2 was 0.97 and the range in lengths used was 126 to 445 mm.

Mortality Rate

The three methods used to estimate the natural mortality rate of sand sole provided estimates of 0.37 to 0.42 yr^{-1} for females and 0.41 to 0.56 yr^{-1} for males (Table 4). For the Hoenig (1983) method, we used a maximum age of 10 years for females and 8 years for males. Since we felt we did not have the true maximum age fish, both ages are greater than the observed maximum ages in our samples (8 years for fe-

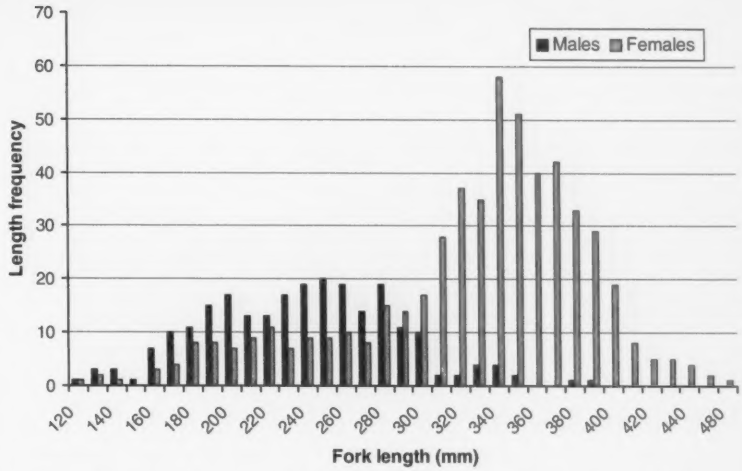

Figure 1.—Length frequency distribution of sand sole collected by research bottom trawls (n=540 for females and 239 for males).

Table 1.—Number of trawl tows conducted, number of tows with sand sole, and total number of sand sole collected from the groundfish ecology cruise program from November 2001 to March 2005, classified by mean depth strata (m).

	Depth strata (m)							
No.	0–19	20–49	50–99	100–149	150–199	200–249	250–299	>299
Tows	8	28	14	23	16	8	8	25
Tows with sand sole	4	31	2	1		1		
Sand sole	171	631	6	2		2		

Table 2.—Catch rate of sand sole by depth bin caught in research bottom trawls.

	Depth bin (m)					
	<20	20–50	50–99	100–149	150–199	200–249
Catch/Tow	23.6	22.8	2.0	0	0	2.0

males and 6 years for males). We used weights of 1.9 and 1.4 kg for females and males, respectively, for the Lorenzen (1996) method. For the Beverton (1992) method, we used a growth rate of 0.60 yr^{-1} for males and 0.79 yr^{-1} for females. We therefore suggest that M is between 0.35 and 0.45 for females and 0.40 and 0.60 for males using the most likely maximum ages.

Total mortality values (Z) for each sex were estimated using catch-at-age from the research samples (Fig. 3). We used a modal age of 2 years of age for males and 3 years for females to represent fully vulnerable fish. The total mortality estimate for males was 0.94 and 0.57 for females.

Table 3.—Estimated von Bertalanffy growth parameters for sand sole with 95% confidence intervals (n=177 for males and n=433 for females).

Sex	Parameter	L_∞	K	t_0
Male	Estimate	310.5	0.60	–0.68
	95% C.I. (±)	33.7	0.34	0.74
Female	Estimate	376.1	0.79	–0.16
	95% C.I (±)	10.6	0.17	0.27

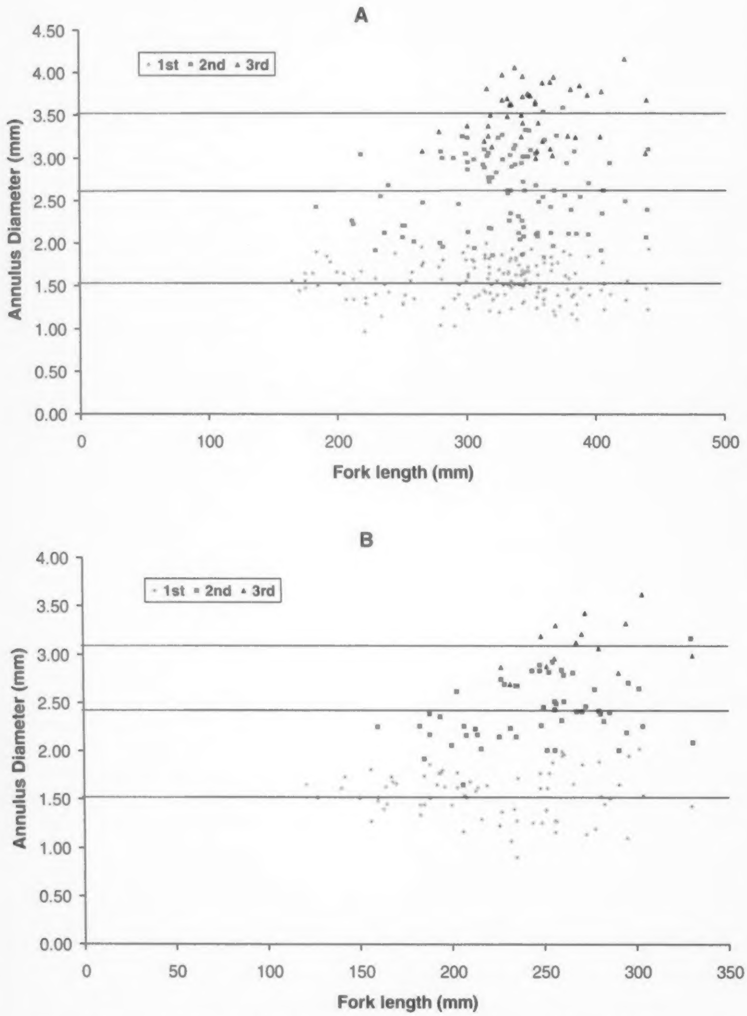

Figure 2.—Diameter of the first, second, and third presumed annulus of female (A) and male (B) sand sole. Horizontal lines indicate mean diameters (n = 151 for females and 75 for males).

Reproduction

Size and Age at Maturity

We found that males mature at a slightly earlier age and smaller size than females. In our study, 87% of 2-year-old females had reached sexual maturity, while over 92% of 2-year-old males were mature (Table 5). Based on our estimated von Bertalanffy growth curves, a 2-year-old male would be about 250 mm while a 2-year-old female would be about 310 mm.

Reproductive Season

An attempt was made in our study to track relative monthly proportions of immature, mature, and spawning fish, but this proved inconclusive due to difficulty in distinguishing maturity stages. The distinction between late ova maturity and early maturity is difficult to distinguish without the aid of a microscope, and individual researchers had different criteria for visually determining the ova stage. Nonetheless, a large proportion of fish taken in January, February, and March were believed to be ripe or spawning.

Sex Ratio

We found a strongly skewed sex ratio in the population, with females constituting 69.3% of the 779 fish for which sex could be determined. Within the 10–40 m depth range, there was no apparent segregation by sex among tows. However, in depths greater than 40 m, only females were caught: one at 60 m and two at a depth of at least 196 m. When we plotted the sex ratio by cohort we found that there has been a substantial decrease in the proportion of females from the 1997 cohort to the 2003 cohort (Table 6).

Table 4.—Estimates of natural mortality rate (M) for sand sole using Hoenig (1983), Lorenzen (1996), and Beverton (1992).

	Mortality rate	
Method	Male	Female
Hoenig	0.53	0.42
Lorenzen	0.41	0.37
Beverton	0.56	0.40

Table 5.—Percent of sand sole that are sexually mature by age (n=126 for males and n=276 for females, from research trawls).

	Age (yr)							
	1	2	3	4	5	6	7	8
Males (%)	73	92	96	100	100	100	100	100
Females (%)	41	82	95	98	100	95	100	100

Table 6.—Sex ratio (percent females) in research samples of sand sole by cohort. Standard errors and sample size for each cohort are shown.

	Cohort						
Item	1997	1998	1999	2000	2001	2002	2003
Percent female	90	84	83	71	62	58	25
S.E.	0.047	0.047	0.040	0.036	0.038	0.058	0.108
No.	40	62	88	157	161	73	16

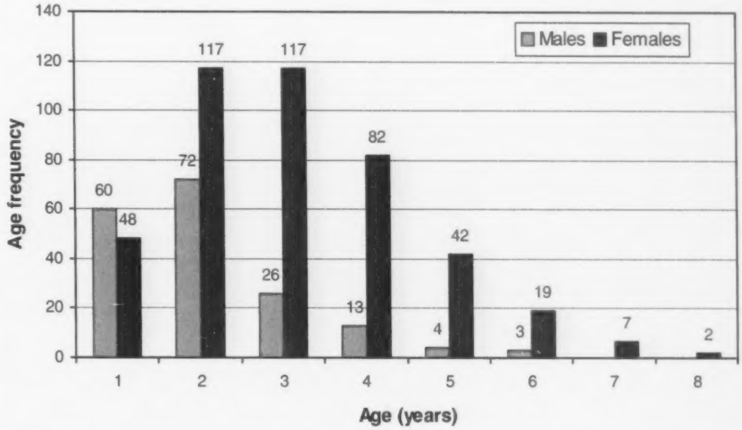

Figure 3.—Age frequency distribution for sand sole collected by the groundfish ecology cruise program (n=178 for males and 434 for females).

Fisheries

Recreational

Recreational landings have declined from a high of 18 t in 1980 to about 2 t in recent years (Table 7) (RecFIN, 2005). Combined annual coast-wide recreational landings have never been greater than 5% of annual coast-wide commercial landings.

Commercial

Commercial landings for California, Oregon, and Washington totaled 4,629 t between 1981 and 2004, with annual landings gradually declining from a high in 1987 (401 t) to an annual average of 97 t during 1999–2004 (Table 7) (PacFIN, 2005). Landings for the Columbia INPFC area were far greater than the other INPFC areas for most of the 1981–2004 time period, comprising a total of 65.5% of all commercially landed sand sole. Landings in areas north and south of the Columbia INPFC area (U.S.–Vancouver and Eureka, respectively) were considerably less, while the Monterey INPFC area had the second highest landings, comprising 17.9% of total landings. Landings from the Conception INPFC area were negligible, comprising just 0.4% of total landings. While the Columbia INPFC area experienced a substantial increase in landings from 1987 to 1994, the other INPFC areas gradually declined.

Trawl logbook data were available for all three states from 1987 through 2005 (PacFIN, 2005). Catch of sand sole was first aggregated by latitude (Table 8), and four regions were selected for further examination based on total catch: lat. 37°N–38°N, lat. 41°N–43°N, lat. 44°N–47°N, and lat. 48°N–49°N. Since these regions were quite similar to the INPFC areas, we used INPFC areas to define our spatial strata. Next, total catch was summed by depth, and it was found that 95% of reported catch occurred in depths of 80 m or less (Table 9). We created four depth strata for our subsequent analyses: 1–20 m, 21–40 m, 41–60 m, and 61–80 m. We also defined five time intervals: 1987–1990, 1991–1994, 1995–1998, 1999–2001, and 2002–2005. The total catch for each region-depth-time bin was then divided by total hours fished to determine the CPUE for each stratum. We found that CPUE was highest for the shallowest depths and decreased with depth (Fig. 4). We also found that the CPUE for the Columbia INPFC area was consistently higher than the other areas. With respect to interannual variability, CPUE decreased somewhat from 1987 through about 1995 and then began to increase, except for the Monterey INPFC area where CPUE remained low.

To confirm that the logbook data accurately represented the fishery, we summed the total pounds reported from the logbook data and compared it to the total reported catch from the landing receipts from 1987 through 2005, for all three states. Results showed that 89% of the landings from landing receipts were reported by the trawl logbooks, suggesting that the logbook data are probably representative of the fishery.

A comparison of the length frequencies from the commercial market samples for northern California (Eureka)

versus central California (Monterey) shows a substantial difference in the length composition, with central California having much smaller fish (Fig. 5). Mean length of fish in central California was 367 mm while it was 407 mm for fish from northern California. Sample sizes were small (169 fish for central California and 121 fish for northern California) and sexes were combined in this comparison. Since the size frequency distributions were so different, we did not attempt to pool them to estimate size and age at recruitment to the fishery. Moreover, since otoliths were not collected from the market samples, it was not possible to examine differences in growth rate.

Discussion

Life History

Adult sand sole are rarely found in estuaries. Smith (1936) noted a high abundance in the northern portions of Puget Sound (i.e. nearer to the ocean), yet they were nearly absent in the lower parts of the Sound (more estuarine). Likewise, Nybakken et al. (1977) found sand sole to be the second most abundant fish at ocean stations located just outside Elkhorn Slough in central California, but no adults were caught in the slough.

Spawning occurs in late winter through mid spring (Smith, 1936; Hickman, 1959). Eggs hatch after about 5 days, although the egg stage may be less in warm water (Hart, 1973). Larvae average 2.8 mm at hatching, and metamorphosis (migration of the left eye and formation of fin rays) is complete at 22–25 mm (Hickman, 1959).

Sommani (1969) found larval abundance to be greatest in July. He also reported the vertical distribution to be evenly distributed about a mean depth of 10–15 m. Boehlert et al. (1985) found evidence of vertical migration, noting that larvae were much more abundant near the surface at night. Rogers (1985) reported that post-metamorphosis juveniles settle out by 30 mm TL in both estuarine (May to September) and offshore habitats (May to August). Although Rogers (1985) found that settlement rate was higher in offshore areas than in estuarine areas, high mortality reduced offshore abundances of settled juveniles to levels similar to that observed for the estuaries.

The larval stage lasts 60–68 days (Thornburgh, 1978), but it is unknown whether this refers to completion of metamorphosis or to the time of settling. Further confounding the issue, Kendall (1966) suggested juveniles might not become demersal upon metamorphosis, but remain as plankton for an extended, unspecified period.

We speculate that 1-year-old fish were underrepresented in this study because Kendall (1966) collected several small specimens (23–51 mm) during beach seines in Puget Sound, indicating that young sand sole may be most abundant in waters shallower than we were able to sample.

Sand sole are active diurnal predators (Miller, 1965) that feed chiefly on small crustaceans while young, switching to a heavily piscivorous diet at around

Table 7.—Annual landings of sand sole for California, Oregon, and Washington. Recreational landings are combined for all INPFC areas (source: RecFIN, 2005). Commercial landings are shown by INPFC area (Conception=CON, Monterey=MNT, Eureka=ERK, Columbia=COL, U.S.–Vancouver=VAN). Source: PacFIN, 2005.

		Commercial INPFC Area				
Year	Recreational	CON	MNT	ERK	COL	VAN
1980	17	N.d.[1]	N.d.	N.d.	N.d.	N.d.
1981	13	4	143	51	45	19
1982	7	2	94	51	107	49
1983	9	0	73	34	29	7
1984	2	0	53	10	33	11
1985	3	0	66	25	93	8
1986	2	0	65	12	69	19
1987	5	0	25	9	357	10
1988	8	0	24	10	176	12
1989	3	0	13	8	244	42
1990	N.d.	0	13	4	238	15
1991	N.d.	0	1	1	317	22
1992	N.d.	0	1	0	206	20
1993	2	0	5	2	216	11
1994	2	0	27	27	173	20
1995	1	0	26	10	78	19
1996	1	3	35	23	70	4
1997	3	1	31	17	83	3
1998	1	0	19	15	43	4
1999	2	0	22	4	79	0
2000	1	0	20	0	22	0
2001	2	0	15	1	40	4
2002	1	0	9	2	103	10
2003	2	0	10	0	104	2
2004	1	0	21	1	122	4

[1]N.d.=no data available

Table 8.—Total trawl logbook catch (in metric tons) of sand sole from 1987 to 2005 (combined) by latitude. Source: PacFIN, 2005.

Lat.	36°	37°	38°	39°	40°	41°	42°	43°	44°	45°	46°	47°	48°	49°
Catch(t)	2	112	414	1	1	139	77	128	473	288	833	492	142	37

Table 9.—Total trawl logbook catch of sand sole from 1987 to 2005 by 10 m depth bin. Catches in 200 m or deeper waters were pooled. Source: PacFIN, 2005.

Depth (m)	20	40	60	80	100	120	140	160	180	200+
Catch (t)	1,485	904	578	72	29	19	20	7	7	32

150 mm (Nybakken et al., 1977; Barry et al., 1996). About 80% of the diet of small sole consists of mysid shrimps (mysidacea), as well as amphipods (amphipoda), decapods (decapoda), and polychaetes (polychaeta) (Nybakken at al., 1977). Larger fish prey on juvenile fish, including sanddabs, *Citharichthys* spp.; sculpins, Cottidae; herring, *Clupea harengus*; tomcod, *Microgadus proximus*; anchovy, *Engraulis mordax*; young sand sole; and squid, Teuthida (probably *Loligo*) (Manzer, 1947; Clemens and Wilby, 1961; Miller, 1965; Barry et al., 1996). Sand sole may reduce or cease feeding during periods of spawning (Smith, 1936; Manzer, 1947), although Miller (1965) challenged this idea, noting that spawning fish in his study did not usually have empty stomachs and found cessation of feeding to be more closely correlated with lower water temperature.

Age and Growth

The maximum age of sand sole is unknown. Manzer (1947) found females from the Vancouver area to be "10 years old or more" but noted that the otoliths "were not clearly enough marked for positive age determination"; therefore, it is uncertain if 10 years is a valid estimate. Demory et al. (1976) found that sand sole in Oregon could reach an age of 10 years; however, they did not

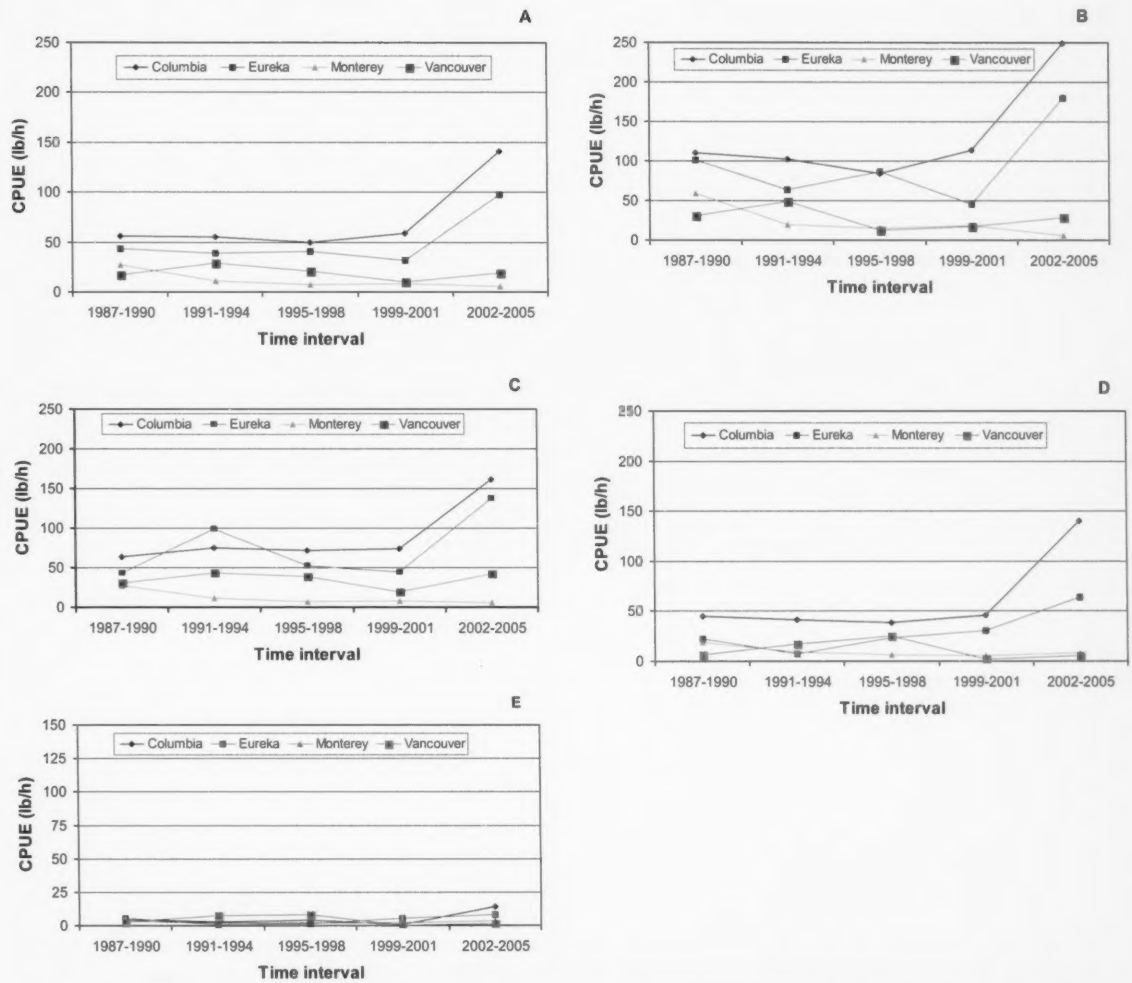

Figure 4.—Catch per unit effort for sand sole from 1987 to 2005 from commercial trawl logbooks. CPUE's were stratified by INPFC area and annual intervals. Panel A = all depths less than 81 m combined, Panel B = 0–20 m, Panel C = 21–40 m, Panel D = 41–60 m, and Panel E = 61–80 m. Source: PacFIN, 2005.

attempt to validate the ages. Since the reported maximum length is 629 mm (Clemens and Wilby, 1961), and since the maximum age fish in this study was 8 years for a 445 mm female fish, we believe that 10 years may be an appropriate estimate of total longevity.

Previous estimates of the von Bertalanffy growth parameters by Demory et al. (1976) have greater K values than our study, showing faster growth in the first 4 years of life (Fig. 6). It should be noted that the trawl used in their study had an 8.9 cm mesh with no codend liner. As a result, smaller fish would not have been retained, tending to select larger, more rapidly growing fish, which could bias their parameter estimates.

Sand sole are said to attain a maximum length of 629 mm and weigh as much as 2,268 grams (Clemens and Wilby, 1961; Kramer et al., 1995), although there is no reference to where fish of this size were observed. Manzer (1947) reports females of 533 mm from Vancouver Island, but does not specify the type of measurement (standard length or fork length). Since the largest fish in our study was 477 mm, and only one study reports fish greater than 533 mm, we suspect that fish greater than 533 mm are very rare in California, Oregon, and Washington.

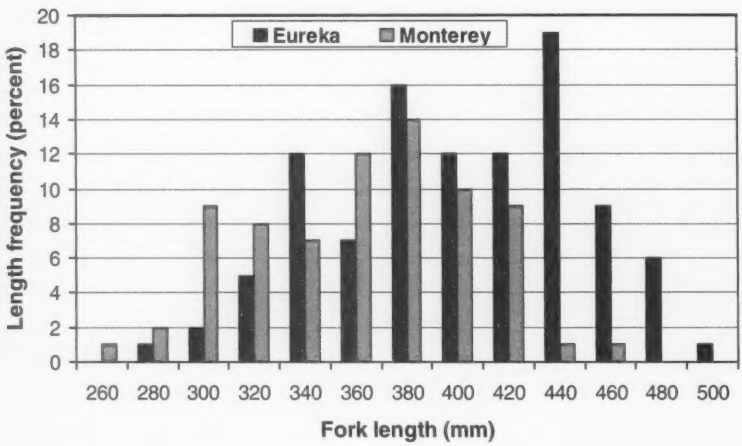

Figure 5.—Length frequency distribution for samples of sand sole from commercial market samples in the Eureka and Monterey INPFC areas. Source: CALCOM, 2005.

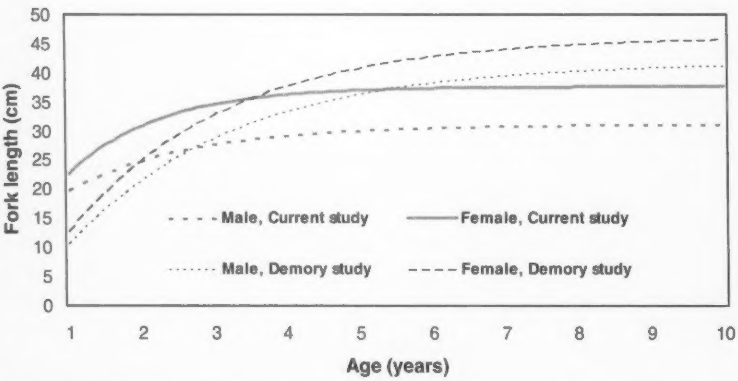

Figure 6.—Predicted von Bertalannfy growth curves from this study compared to those from Demory et al. (1976).

Demory et al. (1976) estimated weight-length relationships for males and females separately using a linear regression model. Converted to an exponential growth model, their estimate was: $W = 0.0171\ FL^{2.848}$, and $W = 0.0113\ FL^{3.129}$ for males and females respectively. Their estimates of a- and b-coefficients for males are similar to ours, as are the b-coefficients for females. However, their a-coefficient for females (0.0113) is 1.68 times greater than ours, suggesting that Oregon females may be heavier than California females of similar length.

Rogers (1985) estimated a relationship of $W = 0.00514\ FL^{3.114}$ (sexes combined) for fish ranging in length from 2.6 to 45.1 cm. As this estimate was taken from a survey of juvenile flatfish, and the mean length of fish in that study was only 11.1 cm, it is possible that this equation is more appropriate for small fish. Although Rogers (1985) did not specify the type of measurement, it probably was total length based on other results presented in the paper.

Reproduction

Smith (1936) found that 100% of 2-year-old males and 3-year-old females (a total of 14 fish) were mature, although he noted that gear selectivity failed to retain fish smaller than 200 mm. These results are similar to our findings.

Sand sole spawn mainly in late winter and spring (Smith, 1936; Hickman 1959). Smith (1936) found females spawning between February and April in Puget Sound, Wash., with peak spawning in March, and noted that males were in spawning condition as early as 1 month prior to females. Hickman (1959) found pelagic eggs locally abundant from January to March in Puget Sound. Sand sole may occasionally spawn later in the year, since Manzer (1947) reported specimens spawning in July around Vancouver Island, Canada.

Garrison and Miller[2] (cited in Casillas et al.[3]) stated that a female of 26 cm may produce 900,000 eggs, while a fish of 37 cm may produce 1,400,000 eggs. They did not report, however, what their sample size was for estimating fecundity.

Examination of previous reports supports the existence of a skewed sex ratio: Smith (1936) and Manzer (1947) caught, respectively, 78% females (n = 97) and 60% females (n = 43), although they did not explicitly report this finding. Although males are generally smaller than females (Fig. 1), the trawl net liner used in our study would have caught them had they been present. It is possible that males reside in shallower water (<10 m) or in unfishable habitats. Commercial fishing mortality would tend to select more females due to mesh size restrictions, thus increasing the proportion of males in the population if fishing mortality was affecting the sex ratio. We therefore propose that the skewed sex ratio is real, and not an artifact of sampling. Yamamoto (1999) found that for Japanese sole, *Paralichthys olivaceus*, genetic females will become phenotypic males if exposed to water warmer than 25°C or colder than 15°C during their larval stage. The normal temperature for larval Japanese sole is about 20°C. Goto et al. (2000) found the same effect for marbled sole, *Pseudopleuronectes yokohamae*, and barfin flounder, *Verasper moseri* (Goto et al., 1999).

Fisheries

Sand sole may be particularly abundant off the central Oregon coast. Boehlert et al. (1985) found sand sole larvae to be the most abundant coastal fish on the Oregon coast (within 28 km of the shore) during six plankton tows in 1982. In addition, the CPUE from the logbook data show that catch rates are substantially higher for Oregon than anywhere else on the coast.

The low CPUE (Fig. 4) for central California, and the smaller size in the commercial market samples suggests there is a possibility that stocks in central California may have been subjected to more fishing pressure than those in northern California. Alternatively, habitat quality may be inferior further south. Furthermore, growth rate may be slower in central California than farther north as suggested by the higher growth rates for sand sole in Oregon found by Demory et al. (1976) (Fig. 6), and the larger size of fish in the Eureka commercial fishery.

Further Research

Still unexplored, to our knowledge, are genetic characteristics, spawning frequency, age and size at recruitment into the fishery, and age at first maturity. A sample of fish between the ages of zero and one, either laboratory hatched or wild-caught, would provide more refined validation of otolith growth, and the timing of gonadal development may be determined. In addition, fecundity needs to be more clearly established. Tag and recapture studies with oxytetracycline (OTC) would provide better validation of ages in adult fish than was possible in our study. Finally, additional work needs to be done to establish the preferred habitat of young fish.

The data presented in this paper suggests that although landings are currently low for most of the sand sole's commercial range (Monterey through U.S.–Vancouver INPFC areas), the stock may be in good condition based on the increasing CPUE values in the three northern INPFC areas. The CPUE for the Monterey INPFC area declined over time and has not shown a recovery in recent years, suggesting the population may have experienced heavy fishing pressure there or environmental conditions may have deteriorated. Furthermore, the shift to more males in the population in the Monterey INPFC area suggests that the stock may not recover quickly. There is evidence for a latitudinal gradient in growth based on the Oregon age and growth data as well as the length composition data from the California commercial fishery.

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Human Dimensions of Marine Fisheries: Using GIS to Illustrate Land-Sea Connections in the Northeast U.S. Herring, *Clupea harengus*, Fishery

PATRICIA PINTO DA SILVA and CHARLES FULCHER

Introduction

The social and ecological interactions inherent to marine fisheries are a mystery for many who are not fishermen or members of fishing families. In areas where fishing takes place near the coast, there may be a general awareness and understanding of these interactions as fishing activities become part of the economic, social, and cultural landscape of the community.

Understanding offshore commercial fisheries, however, can be challenging for coastal and non coastal residents alike. Site visits to ports leave many questions unanswered. Vessels come and go along with trucks hauling catch (in many cases already processed, bagged, or packaged) away from ports.

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ABSTRACT—Geographic Information Systems can help improve ocean literacy and inform our understanding of the human dimensions of marine resource use. This paper describes a pilot project where GIS is used to illustrate the connections between fish stocks and the social, cultural, and economic components of the fishery on land. This method of presenting and merging qualitative and quantitative data represents a new approach to assist fishery managers, participants, policy-makers, and other stakeholders in visualizing an often confusing and poorly understood web of interactions. The Atlantic herring fishery serves as a case study and maps from this pilot project are presented and methods reviewed.

Additionally, while nearshore fisheries often supply local markets, larger scale commercial fisheries that commonly fish offshore often cater to markets outside local and even regional boundaries. Distance as well as increased vessel size and mobility present challenges for understanding the interactions between fishers, other fishery participants, and fishing grounds. Given the increased specialization of the fishing industry, one might have a general understanding of one fishery but the social, economic, and ecological connections in another may not be obvious.

Not only do fishing methods differ between fisheries, but the distribution, processing, and marketing of commercial marine resources also varies significantly. Certain fisheries are better understood than others. For example, coastal residents of Maine and elsewhere in New England are likely to have a general understanding of how and where lobsters, *Homarus americanus*, are caught and will certainly be able to recognize the species.

This familiarity is due in part to the fishery's visibility. Lobsters are predominantly caught close to shore and multicolored buoys commonly dot inlets and coastal waters. Owner-operated vessels are moored in harbors and go out daily to check and empty traps. Traps are ubiquitous—stacked in backyards, on piers, and even used as coffee tables in summer homes. And, of course, live and cooked lobsters and lobster products are widely available at the local fishmonger and restaurants.

Social and ecological interactions in most fisheries are much less obvious to fishery stakeholders. Fisheries in the northeastern United States such as herring, *Clupea harengus*; squid, *Loligo vulgaris;* monkfish, *Lophius americanus;* cod, *Gadus morhua;* and other groundfish species are examples of this disconnect. Some fisheries have few participants and are highly localized, landing their catch in a limited number of ports, while others have thousands of participants scattered along the coastline with catch being distributed throughout the region. While one species might be processed, packed, distributed, and consumed locally, another might be frozen and shipped abroad for international consumption. Understanding these land-sea linkages and social networks is essential to understanding the human component of the ecosystem as well as comprehending how changes in the condition of the resource or regulations might impact coastal communities and other stakeholders in the short term and over time.

Mapping Socio-Ecological Marine Connections

Analysis of economic and social impacts of fishery regulations is required by the National Environmental Policy Act and by the Magnuson-Stevens Fishery Conservation and Management Act, with the latter emphasizing the need to understand the history of the fishery and impacts on fishing communities (National Standard 8). Each fishery management plan or amendment to a plan must include a description of the potentially "affected human environment." Ideally, this information is used as a baseline against which sociocultural and economic changes experienced by stakeholder groups and relevant communities can be measured over time.

A common criticism of these documents is that they are too long, complicated, and inaccessible to the average fishery stakeholder. A recent Federal court decision in a challenge to Amendment 13 of the Northeast Multispecies Fishery Management Plan found that while the content of the document met legal requirements, it was less successful at "disclosing information in terms intelligible to interested members of the public, public servants, and legislators."[1] The total length of this document was over 1,500 pages with the "affected human environment" section of the document comprising over 350 pages (NEFMC, 2003).

Formal analysis of fishing activities is generally limited to either at-sea activities or the economic impacts of regulatory changes on fishing businesses. Only recently have research efforts focused on the social and cultural impacts on fishermen, their families, and other fisheries stakeholders such as coastal communities. Traditionally, the types of data about fishery participants available in government databases have focused on vessels and landings.

Socio-cultural data is only now beginning to be acquired. One example of this is the baseline demographic data on coastal communities now being collected to better document social change over time (Federal Register, 1998). Rarely, however, is there a connection drawn between the marine resource and coastal stakeholders at any scale to evaluate how environmental or regulatory changes might impact a region. One notable effort to address this gap is the development of an economic impact model capable of predicting multiplier effects of proposed fishery management actions on subregions in the northeast United States (Steinback and Thunberg, 2006).

GIS and the Human Dimensions of Marine Ecosystems

The use of Geographic Information Systems (GIS) in fisheries science and decision-making has occurred slower than in other fields of resource management (Isaak and Hubert, 1997; Meaden, 2000; St. Martin, 2004). However, recently applications have begun to grow exponentially and GIS is increasingly being used as a tool for understanding marine ecosystems (Meaden and Do Chi, 1996; Meaden, 1996; Valavanis, 2002; Fisher and Rahel, 2004). Increased peer-reviewed publications, numerous sessions at fisheries conferences dedicated to the subject, and, in 2005, the third international symposium on GIS in fisheries science are all testimony to the increasing interest in this subject area. A review of these publications and conference proceedings, however, shows that much of the work carried out to date has been focused on the biological and oceanographic aspects of marine ecosystems.

In marine applications, GIS usage by social scientists has generally lagged that of physical scientists, leading to a fundamental disconnect between the disciplines with respect to GIS applications. While biologists, ecologists, oceanographers, and the like are moving from the static representation of data to dynamic GIS-based modeling of the environment, social scientists are still attempting to find the best methods of displaying data in a static and yet meaningful manner. This is likely an important reason for the lack of efforts to visualize land-sea connections, and more communication may be necessary between the disciplines to find the best way of incorporating static socioeconomic data into the dynamic models being developed by physical scientists. At the same time, and more importantly, social scientists must press onward and develop more dynamic representations of the diverse socioeconomic data available.

There has been some progress along these lines in nonmarine applications, especially in regional science literature. Goodchild and Haining (2004) note that GIS and spatial data analysis were once separate fields of research, but they have converged over time. While this may be encouraging, applications are typically statistical in nature, like those embraced by practitioners of the physical sciences.

What is needed is a method of incorporating within these statistical exercises the wealth of data available from community profiles. Further, there are implications for the types of questions asked and data collected when completing community profiles. Recognizing that GIS is capable of displaying data of both quantitative and qualitative varieties, as long as the data are collected in a systematic manner and can be related to a geographic place, community profiles should be structured in a manner facilitating the use of GIS as a representational tool.

Participatory GIS applications dealing with marine resources typically focus on such exercises as mapping fishing grounds and fishermen's perceptions of the physical characteristics of the marine environment. While these are useful and may help guide fishery management by identifying the concerns of resource users, they are nonetheless focused on the sea. What we envision is a similar display of information about the fishing communities on land and their connection to marine resources. Only through an understanding of these linkages can we protect marine resources while also understanding the impact of protective management measures on fishing communities and other stakeholders.

GIS has been used to study a wide range of topics pertinent to fisheries and their management. Topics frequently encountered in the literature include habitat assessment and management, aquaculture and mariculture site selection, mapping oceanographic features, and population dynamics. Under the latter category are found such applications as abundance and spatial distribution mapping, as well as movement tracking, such as sightings of right whales, *Balaenidae eubalaena,* or migration patterns of yellowtail flounder, *Limanda ferruginea.* The growing number of tagging projects and increased funding for habitat mapping reflects the increasing prevalence of these applications. Applications of GIS for understanding the human dimensions of marine ecosystems, however, have only begun to evolve.

[1]Oceana v. Evans, Civil Action No. 04–0811, D.D.C. 9 March, 2005, p. 42.

Table 1.—Current applications of GIS in marine fisheries.

Category	Study types	Data sources	Examples
Remote sensing	Marine productivity hotspots Aquaculture site selection Population dynamics	Airborne sensors Space-based sensors Radar Underwater sensors Aerial photography	Karthik et al., 2005 Valavanis et al., 2004 Pérez et al., 2003a
Spatial visualization	Macro: World fisheries Consumption by country Production by country	FAO statistics	FAO, 2003, 2004, 2005 Watson, 2004
	Regional: Permitted vessel by county Registered vessels by size Landed value by county Poverty rates by county Fishing effort by state Value by place Landings by port Fishing activity Effects of closures on behavior Fish movement tracking Stakeholder conflict mapping	Permit data Landings data Census data Vessel logbooks Tag returns/reports Location databases	St. Martin, 2004 Brody et al., 2003 Olson, 2003 NE Reg. Cod Tagging Prog. (text footnote 2) Edwards et al., 2001 Walden et al., 2001 Caddy and Carocci, 1999 Kemp and Meaden, 2002
Participatory GIS	Delineation of fishing grounds Local ecological knowledge	Surveys Interviews	Scholz et al., 2004 St. Martin, 2001 Macnab, 2002 Anuchiracheeva et al., 2003 Close, 2003 Close and Hall, 2006

GIS applications can be broadly grouped into three varieties: remote sensing of phenomena or patterns from afar, the spatial representation of data, and participatory GIS, which involves asking stakeholders their opinions as to the location of activities. Table 1 presents some examples of the types of studies within each of these categories.

Remote sensing may be defined as the acquisition of data about an object or phenomenon from afar. Airborne or space-based sensors, radar, aerial photography, and underwater sensors have all been used in remote sensing of marine phenomena, such as the identification of marine productivity hotspots (Valavanis et al., 2004), aquaculture site selection (Perez et al., 2003a; Perez et al, 2003b; Karthik, et al., 2005), or the tracking of species for studies of population dynamics. Simpson (1992) and Butler et al. (1998) provide useful introductions to the technical aspect of remote sensing in fisheries. There are relatively few applications attempting to integrate remote sensing into social science (Liverman et al., 1998; Hall et al., 2001). Of those that have focused on land-based activities, there are none to our knowledge that have focused on fisheries.

Another method used to track species movement has been the use of implanted tags, which are then returned by the person catching the tagged fish. The person provides information about where the fish was caught, and this information can be entered into a GIS. One initiative using this technique is the Northeast Regional Cod Tagging Program[2], which began in March 2003 and has tagged over 100,000 fish. This technique falls under the broad category of spatial representation of data, which has been the primary use of GIS in marine fisheries.

To date GIS has not become an integral part of the fisheries management process, though some maps have been produced for this purpose and demonstrate the utility and power of this medium to visually depict human interactions with different fisheries. Examples include using vessel trip report and census data to map total landings by place, total catch value by place, fishing activity by state, poverty rates by county, registered fishing vessels by size, landed value by county, or permitted vessels by county (Caddy and Carocci, 1999; Kemp and Meaden, 2002; Olson, 2003).

In economics, efforts have included the use of GIS coupled with economic models to predict the behavior of fishing fleets. Not only can catch locations be mapped but economic models help predict behavior changes of fleets faced with different area restrictions on their fishing activities (specifically groundfish fleets on both the U.S. east and west coast) (PMCC/Ecotrust, 2003; Walden et al., 2001). They have also been used to understand the economic impacts of area closures (Edwards et al., 2001).

On a macro level, GIS maps have been used to present global trends in fisheries, presenting information that helps illustrate distribution issues and access issues related to the world's fisheries (FAO, 2003, 2004, 2005; Watson, 2004; Watson, et al., 2004). These applications have a heavy focus on what occurs at sea without much attention paid to how these activities interact with land based activities or onshore activities. Land areas are usually presented as a colorless mass separated from the ocean with a black line. St. Martin (2006) (Fig. 1)

[2]http://codresearch.org/

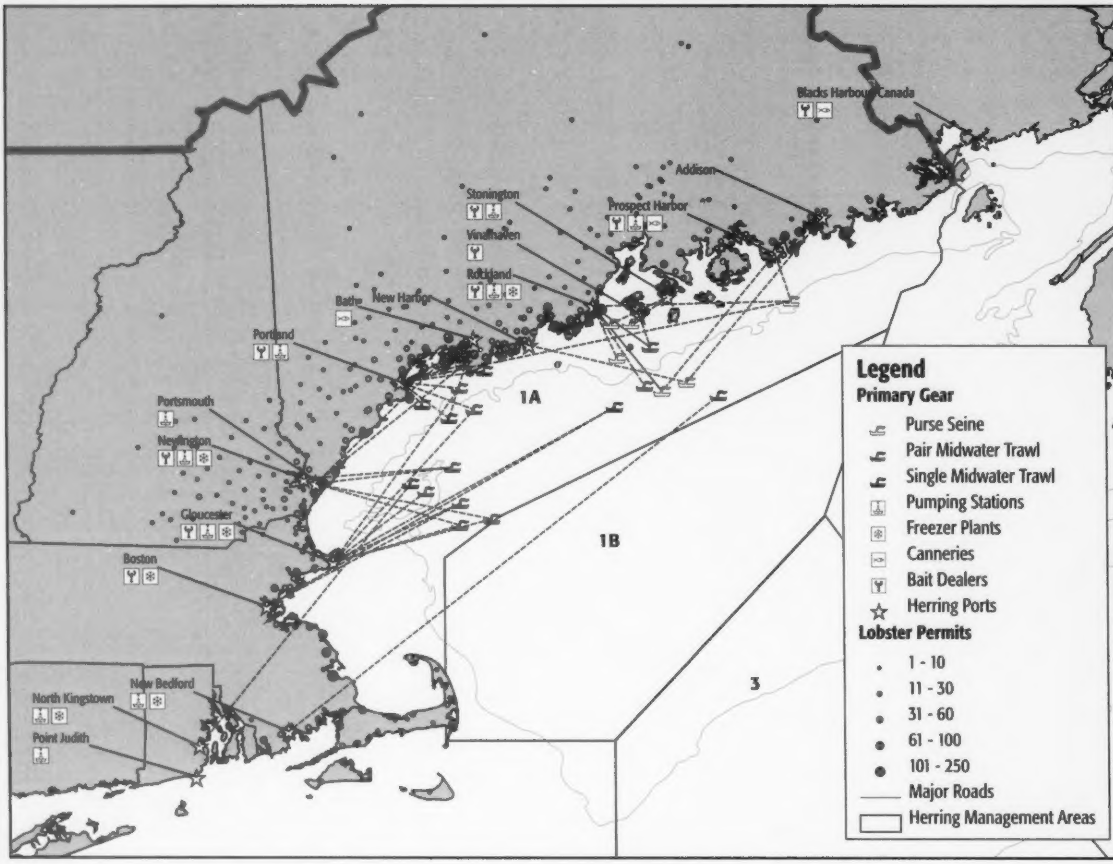

Figure 1.— Herring Management Area 1A summer/fall activity, 2000–03.

notes that the maps of fishing effort typically employed by NMFS and the regional fisheries management councils indicate where the vessels went when absent from shore, but the communities from which particular boats originate are not shown.

The use of surveys and interviews of local users of a resource to identify the spatial extent of an area or phenomenon is a technique used in participatory GIS. In marine fisheries, these studies have typically focused on the delineation of fishing grounds and the mapping of local ecological knowledge (Macnab, 2002; Anuchiracheeva et al, 2003; Scholz et al., 2004; Brody et al., 2005). St. Martin (2001) maps fisheries in terms of the perceptions of participants and scales of operation, noting that this reveals the landscapes of fishing communities and leads to suggestions for area-based management which has the potential to facilitate community development. Weiner et al. (2002) also note the important role that community participation can play in the development of GIS application, while Close (2003) and Close and Hall (2006) offer technical advice for integrating local knowledge and GIS for fisheries management.

Herring Fishery Pilot Project

The studies by St. Martin (2001) and Macnab (2002) are similar in spirit to the work presented herein. The herring fishery pilot project presented below attempts to merge two of the broad areas of GIS applications discussed above by including within a common framework of data collected by government agencies and the knowledge of the fisheries possessed by resource users. The herring fishery offers a new way of illustrating land-sea connections and demonstrates that a hybrid approach to GIS incorporating both qualitative and quantitative data can be an important tool for understanding the links between marine resources and human communities.

The impetus for this pilot project was the development of an Affected Human Environment Statement for Amendment 1 to the Atlantic Herring Fishery Management Plan prepared by the New England Fishery Management Council.

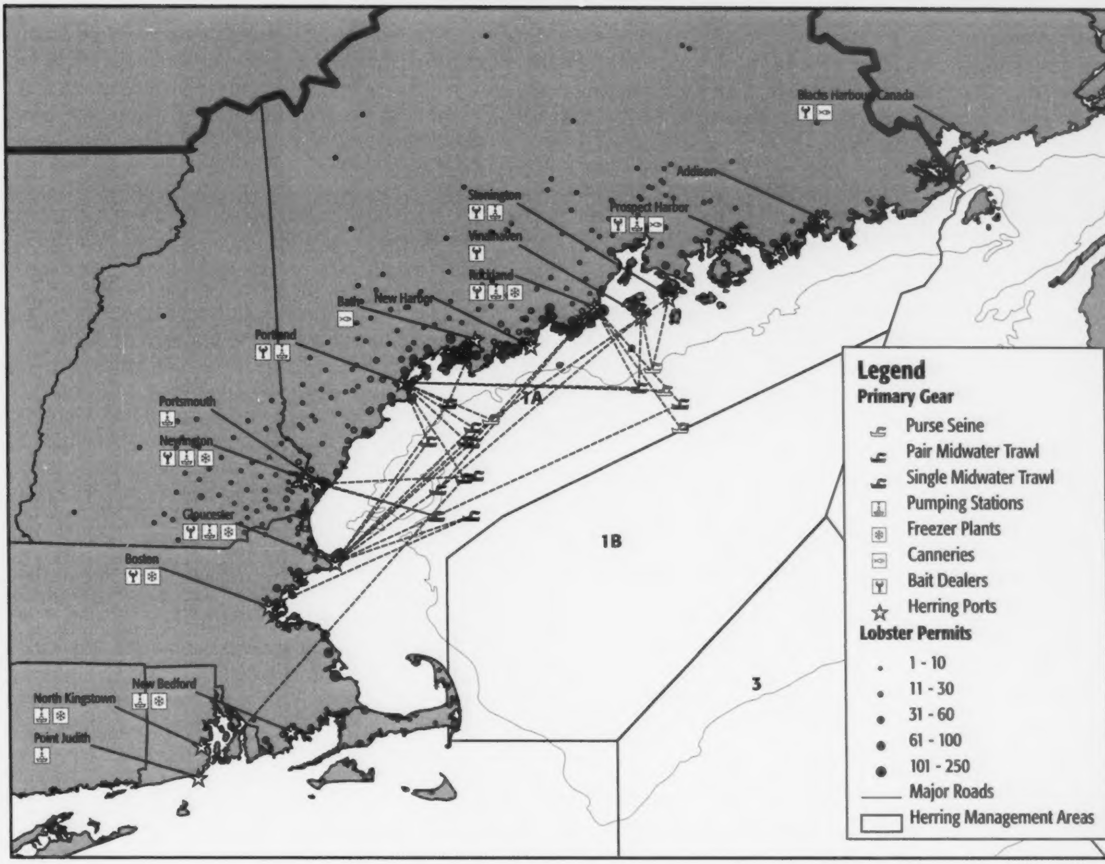

Figure 2.—Herring Management Area 1A winter/spring activity, 2000–03.

Currently[3], the herring fishery is an open access fishery managed by quotas and divided into four separate areas (1A, 1B, 2, 3) each with its own total allowable catch (TAC). Key measures in the Amendment are limiting access to the fishery and the creation of a seasonal purse seine/fixed gear only area in the northern part of Area 1A.

Implementation of these measures will impact current and future access to the fishery, and the distribution of potential catches among stakeholders. Given this, the primary purpose of the GIS-based analysis was to identify and illustrate the linkages between herring stocks in management Area 1A and fishery stakeholders in New England. This information will serve as a baseline from which to predict changes and impacts to stakeholders and to analyze future changes to the fishery. The maps produced focus on fishing effort in Area 1A, which is the prime location for the summer fishery that supplies the bait markets for the American lobster fishery and the herring cannery[4] in the region. Area 1A is also the only herring management area where the TAC is consistently attained.

Figures 1 and 2 illustrate the herring fishery in terms of geographic distribution, gear type, processing types, and key ports. Data for these maps were obtained from various sources. Herring landings were provided by the State of Maine, while vessel trip reports indicating catch, gear type, and fishing location came from NMFS databases. The number of lobster permits in each town in Maine, New Hampshire, and Massachusetts was provided by the respective state, and it was included to identify individuals who could be most impacted by changes in the availability of herring. Major roads were included to indicate possible trucking routes for the distribution of herring to more remote coastal areas. The locations of primary herring

[3]Amendment 1 to the Herring FMP is currently being reviewed by the National Marine Fisheries Service and will likely go into effect in 2007.

[4]Currently the herring cannery in Prospect Harbor, Maine, is the only facility of its kind in the region.

ports and support facilities (pumping stations, freezer plants, canneries, and bait dealers) located at or near those ports also appear on the maps.

The maps were created using the ArcView 8.3 GIS system. As the fishery undergoes seasonal changes, separate maps were generated for the winter/spring (December–May) and summer/fall (June–November) seasons. Total landings for each vessel were summed over the 2000–2003 period to determine the primary vessels within the fishery, and 34 vessels accounted for 99.5% of the landings during this period. To ensure that these vessels represented regular participants in the fishery, an additional requirement was that the vessels made at least 20 trips within the combined management areas during the period. For each of these 34 vessels, the primary gear used during each season in each management area was identified, as well as the port where they unloaded the largest percentage of their catch during the winter/spring and summer/fall seasons.

The maps are meant to be illustrative in nature, rather than a specific representation of fishing activity at any particular point in time. That said, the location of each vessel on the map was chosen to minimize the distance between the trip locations reported in the vessel logs and the port where the vessel unloaded the largest percentage of its catch. However, the locations should not be construed as indicating any vessel's particular fishing pattern.

Having created a point for each vessel, lines were drawn to each port where the vessel landed herring while fishing in that management area during that particular season. Again for clarity of presentation, a vessel had to have landed at least 10% of its catch in a particular port for a line to be drawn to that port. Then, the map symbol for each vessel was changed to indicate its primary fishing gear (single midwater trawl, pair midwater trawl, or purse seine).

Ideally, these maps provide the reader with a one page snapshot of the land-sea connections related to the herring harvested from Management Area 1A. Key communities related to this fishery are mapped and are shown with icons next to them indicating what herring-related infrastructure existed in that location. For example, both figures show that Gloucester, Massachusetts; Newington, New Hampshire; and Rockland, Maine have pumping stations, bait dealers, and freezer plants. Dots show concentrations of lobster permit holders in New England states with Maine clearly having the greatest number and consequently the greatest dependency on herring as a source of bait. The maps identify three primary destinations for herring from Area 1A—lobster dealers/bait dealers, sardine canneries, and freezer plants.

The maps show the connection between vessels and ports. The maps also depict the distribution of gear types used in different regions. For example, purse seine vessels are largely linked to more northern ports (such as Rockland and Prospect Harbor, Maine) while pair and midwater trawlers are concentrated in southern ports and linked to ports with processing and freezing facilities.

Clearly, these maps are an oversimplification of the herring fishery, but they provide the reader with a point of departure to explore social, economic, and ecological aspects of the fishery. Coupling maps with descriptions of the ports, communities, businesses, and other stakeholders should help to contextualize them. Future web-based improvements could be aimed at presenting this information in a more user-friendly way allowing users to explore the maps by clicking on icons of particular interest to them.

Conclusion

Research and analysis for fishery management plans is usually grouped into three areas: biological, social, and economic. Typically, information in each area is independently analyzed, presenting an artificial disaggregation of related information. Improving our understanding of social, economic, and ecological marine connections is critical to linking people to the marine environment and understanding the role of humans and human communities in ecosystem-based management. Single-species management has made these separations even more pronounced in that analyses are only related to one species or a group of species.

Fisheries management can benefit from an improved ability to visualize these connections, as social and economic impacts of regulatory changes can then be more quickly analyzed and accessible to a wider audience. GIS maps can show a scale of information otherwise inaccessible along with layers of information illuminating social and ecological networks that are poorly understood. Interactive web-based tools should increase the usefulness of this approach as these will allow for increased layering, options, and better integration of qualitative and quantitative data.

In addition, while it is increasingly difficult to make sense of long text-based reports on impacts and changes to a fishery, maps like this one could be used as "visual baselines" to measure changes in a fishery over time. The benefit is that much could be gleaned by simply comparing or overlaying maps from two different time periods. By making these maps web based and interactive, quantitative information could be accessed alongside qualitative data. For example, clicking on a key port icon could link the viewer to the community profile for that port that would include sociocultural and economic information for that location. Text-based information related to the Affected Human Environment of this fishery could also be linked to each icon. Such information might include site visits, structured and unstructured interviews with fishery participants, existing literature, census data, and web links. Over time, even photos and video could become illustrative elements of these interactive documents. For the purposes of the Affected Human Environment statement for Amendment 1, demographic profiles of key port communities; descriptions of each of the processing plants, canneries, and bait dealers; and information on the different gear types associated with this fishery were provided for readers to gain a deeper understanding of the stakeholders involved in this fishery.

While GIS can be a powerful analytical tool, it is unable to escape data limitations. GIS maps are only as good as the information that fuels them. While this approach worked well for the herring fishery, it may need to be adapted to work for other fisheries with different characteristics. For example, applying this method for a fishery like the northeast groundfish fishery may be complicated as the large number of vessels participating in the fishery are increasingly being managed though several different access privileges (i.e. days-at-sea, special access, and sector quotas). The large number of vessels involved may present challenges for this approach, as some aggregation of vessels by size class, gear type, or homeport will be necessary for the maps to be intelligible.

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Errata

Witherell, David, and Doug Woodby. 2005. Application of Marine Protected Areas for Sustainable Production and Marine Biodiversity off Alaska. Marine Fisheries Review 67(1):1-27.

On page 3, the paper noted that, in 1961, Japan established a no-trawl zone in Bristol Bay. This closure was actually first established in 1959.

On page 11, the western boundary of the Nearshore Bristol Bay Trawl Closure Area was identified as long. 163°W; the correct boundary is long. 162°W.

We thank Mr. Braxton Dew for noting these corrections.

D. Witherell and *D. Woodby*

Editorial Guidelines for the *Marine Fisheries Review*

The *Marine Fisheries Review* publishes review articles, original research reports, significant progress reports, technical notes, and news articles on fisheries science, engineering, and economics, commercial and recreational fisheries, marine mammal studies, aquaculture, and U.S. and foreign fisheries developments. Emphasis, however, is on in-depth review articles and practical or applied aspects of marine fisheries rather than pure research.

Preferred paper length ranges from 4 to 12 printed pages (about 10-40 manuscript pages), although shorter and longer papers are sometimes accepted. Papers are normally printed within 4-6 months of acceptance. Publication is hastened when manuscripts conform to the following recommended guidelines.

The Manuscript

Submission of a manuscript to the *Marine Fisheries Review* implies that the manuscript is the author's own work, has not been submitted for publication elsewhere, and is ready for publication as submitted. Commerce Department personnel should submit papers under a completed NOAA Form 25-700.

Manuscripts must be typed double-spaced throughout and submitted with two duplicate copies. The complete manuscript normally includes a title page, a short abstract, text, literature citations, tables, figure legends, footnotes, and the figures. The title page should carry the title and the name, department, institution or other affiliation, and complete address (plus current address if different) of the author(s). Manuscript pages should be numbered and have 1-inch margins on all sides. Running heads are not used. An "Acknowledgments" section, if needed, may be placed at the end of the text. Use of appendices is discouraged.

Abstract and Headings

Keep titles, headings, subheadings, and the abstract short and clear. Because abstracts are circulated by abstracting agencies, it is important that they represent the research clearly and concisely. Headings within each section must be short, reflect a logical sequence, and follow the rules of multiple subdivision (i.e. there can be no subdivision without at least two items).

Style

The entire text should be intelligible to interdisciplinary readers; therefore, all acronyms, abbreviations, and technical terms should be spelled out the first time they are mentioned. The scientific names of species must be written out the first time they are mentioned; subsequent mention of scientific names may be abbreviated. Follow the U.S. Government Printing Office Style Manual (1984 ed.) and the CBE Style Manual (5th ed.) for editorial style, and the most current issue of the American Fisheries Society's Common and Scientific Names of Fishes from the United States and Canada for fish nomenclature. Only journal titles, scientific names (genera and species), and vessel names should be italicized. Dates should be written as follows: 11 Nov. 1991. Measurements should be expressed in metric units, e.g. metric tons as t; other equivalent units may also be listed in parenthesis. Common abbreviations and symbols such as mm, m, g, ml, mg, and °C (without periods) may be used with numerals. The numeral one (1) should be typed as a one, not as a lowercase el (l). Write out the numbers zero through nine unless they form part of measurement units (e.g. nine fish but 9 mm).

Footnotes

Footnotes should not be embedded within the text document. They must be numbered with Arabic numerals and typed on a separate sheet of paper. Footnote all personal communications, listing the name, affiliation, and address of the communicator and date of communication. Unpublished data and unpublished manuscripts should include the title, author, pagination of the manuscript or report, and the address where it is on file. Authors are advised to avoid references to nonstandard (gray) literature, such as internal, project, processed, or administrative reports, wherever possible. Where these references are used, please include whether they are available from NTIS (National Technical Information Service) or from some other public depository.

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Title the list of references "Literature Cited" and include only published works or those actually in press. Citations must contain the complete title of the work, inclusive pagination, full journal title, and the year, month, volume, and issue numbers of the publication. Unpublished reports or manuscripts and personal communications must be footnoted.

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Tables should be printed separately and double-spaced. Tables should not be excessive in size and must be cited in numerical order in the text. Headings should be short but sufficent to allow the table to be intelligible on its own. All unusual symbols must be explained in the table heading. Other incidental comments may be footnoted with Arabic numerals. Because tables are typeset, they need only be submitted typed and formatted, with double-spaced legends. Zeros should precede all decimal points for values less than one. Table headings and format should be consistent; do not use vertical rules.

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Figures include line illustrations and photographs (or slides) and must be cited in numerical order in the text. Figures are to be labeled with author's name and number of figure. Use Times Roman font (upper and lowercase letters) to label within figures. Avoid vertical lettering except for y-axis labels. Zeros should precede all decimal points for values less than one. Figures should be submitted as both laser-printed copies and computer software files. Figure legends should explain all symbols and abbreviations and should be double-spaced on a separate page at the end of the manuscript. Consider column and page sizes when designing figures. Please note that we do not print graphics in color.

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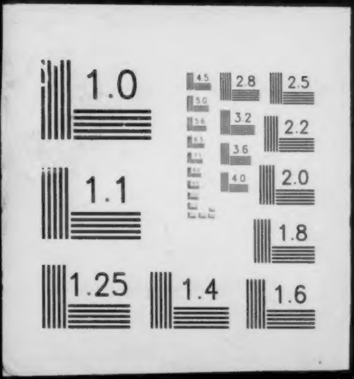
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